Imaging the Developing Human Brain

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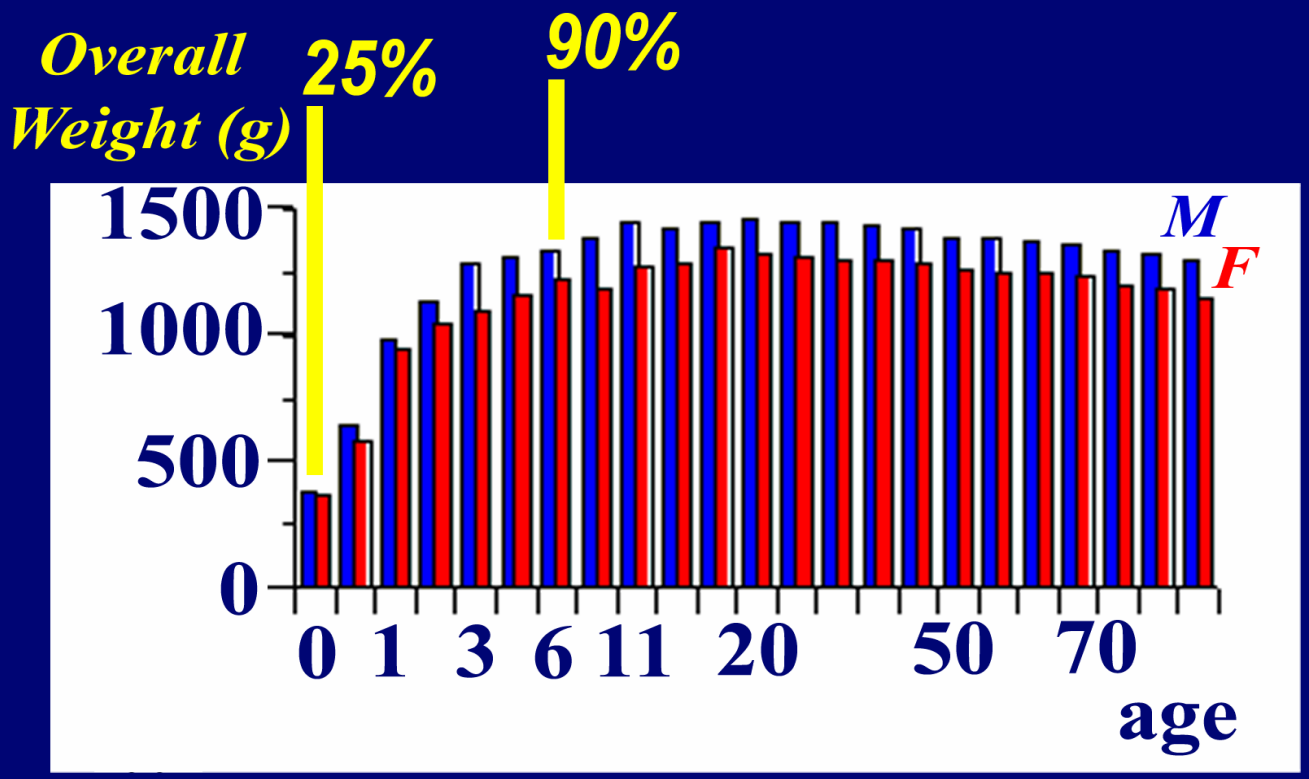
Brain Development: The Questions

How does the brain change during childhood? During adolescence?

Can we detect spatial and temporal patterns that help explain cognitive and social development during various maturational stages?

Growing Brains



Geigy Scientific, 1970

The brain has reached 90% of its adult value by approximately 7 years

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Given that relatively little change is occurring in overall measures of brain growth, it might be more interesting to look at the dynamic changes going on within various brain tissues such as gray and white matter during the child and adolescent years.

Sculpting the Postnatal Brain

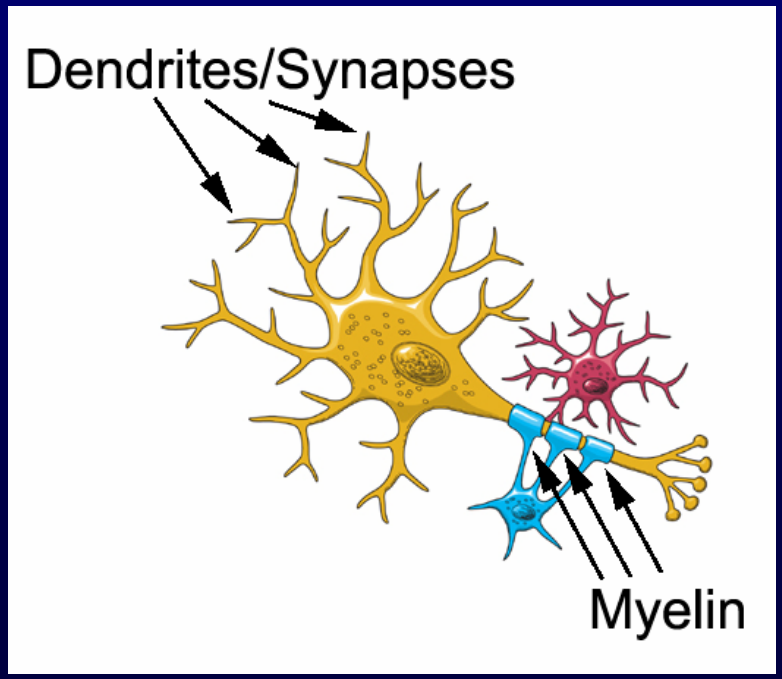
What kinds of cellular changes are occurring that could give rise to the dynamic brain changes we observe during childhood and adolescence?

Myelination (increased speed of transmission).

Synaptic pruning (increased efficiency-decreased plasticity).

Synaptogenesis?

Neurogenesis?



Only post-mortem and animal studies can tell.

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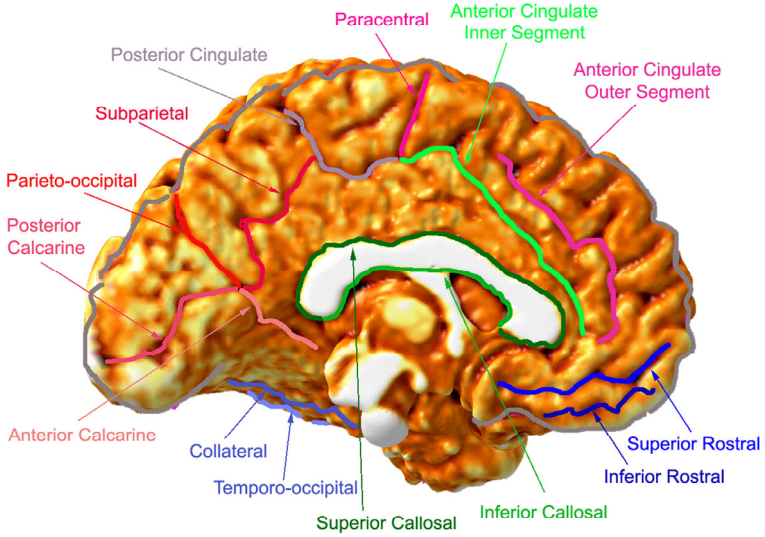
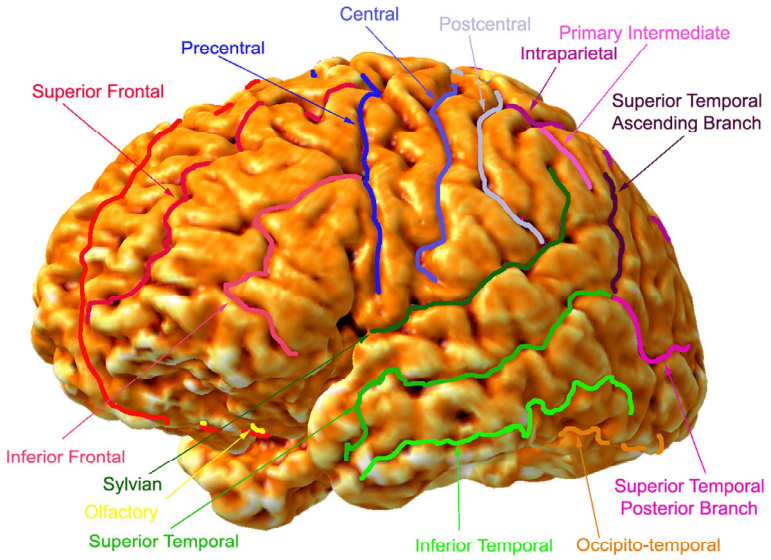
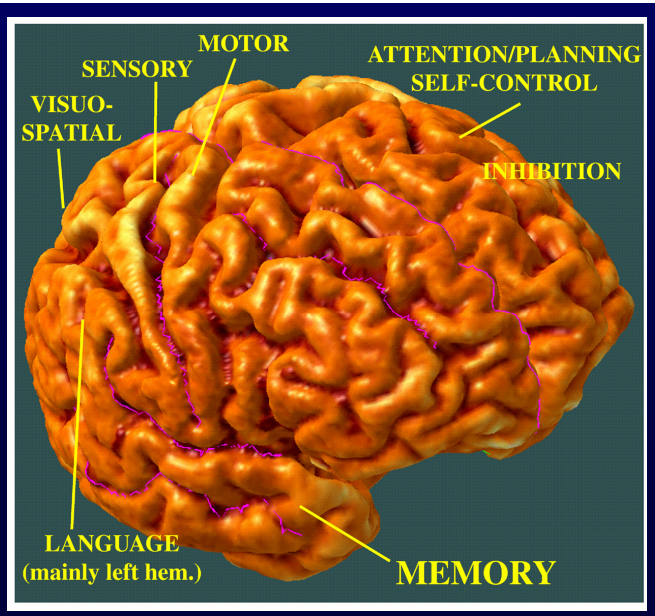
Surface Based Methods







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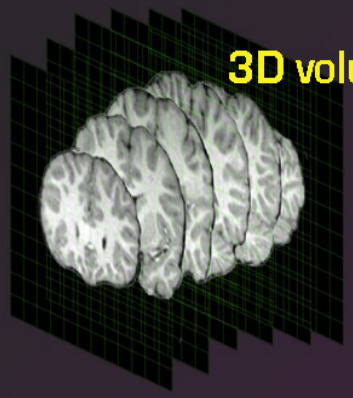
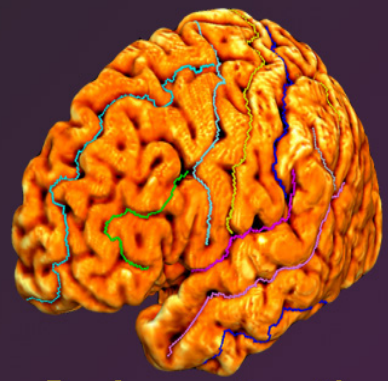
Surface Creation, Flatmapping, and Warping

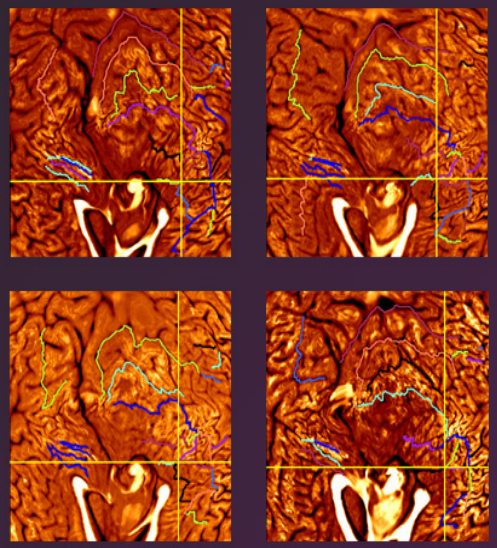
3D volume

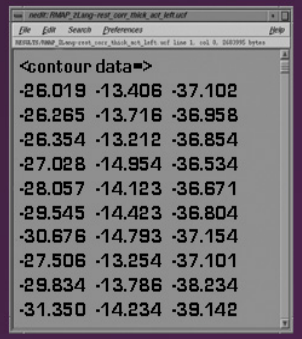




Surface extraction and curve drawing

Flatmaps and warping





3D Cortical UCF file

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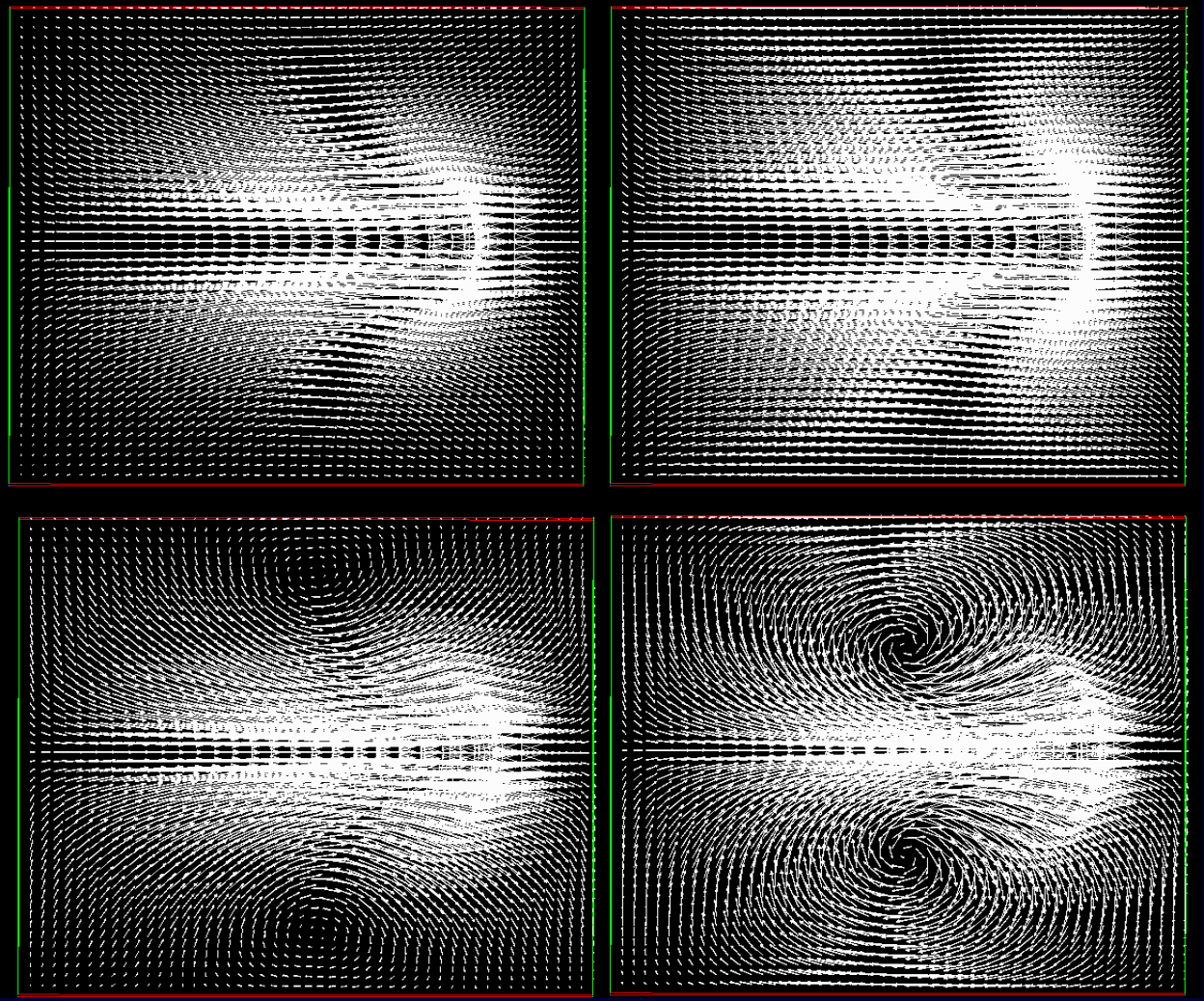
The Navier equation for elastostatics to evaluate small deformations required to warp the brain data from one individual into a group atlas where we can begin to evaluate group differences in anatomy or function.

$$(\lambda+\mu)\,\nabla(\nabla\bullet u(x))+\mu\nabla^2 u(x)+F(x-u(x))=0$$



Courtesy of Paul Thompson

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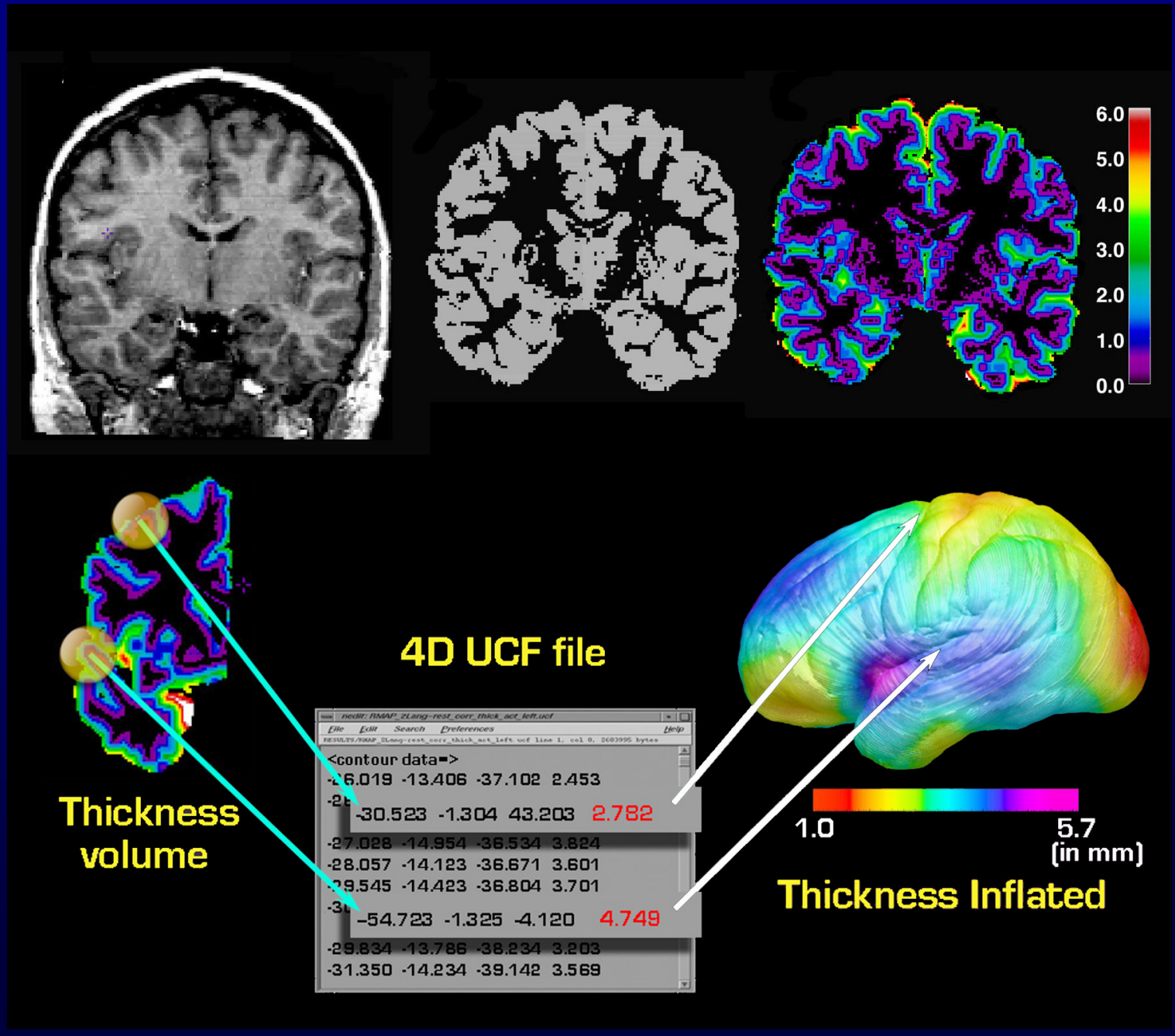
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4D UCF file
Thickness volume
<contour data=>
-30.523 -1.304 43.203 2.782
-27.028 -14.954 -36.534 3.824
-28.057 -14.123 -36.671 3.601
-54.723 -1.325 -4.120 4.749
-29.834 -13.786 -38.234 3.203
-31.350 -14.234 -39.142 3.569
1.0
5.7
(in mm)
Thickness Inflated
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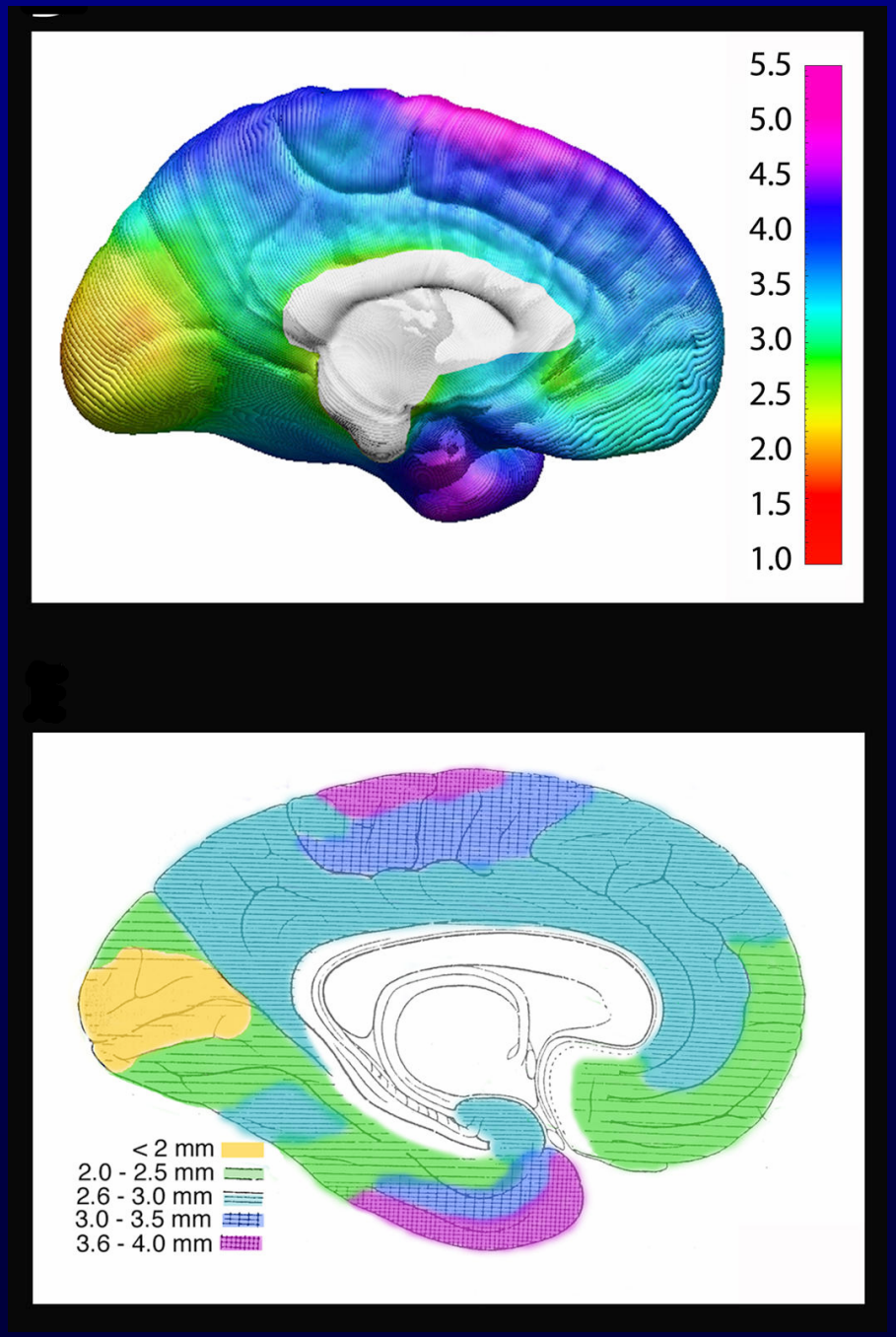
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
< 2 mm
2.0 - 2.5 mm
2.6 - 3.0 mm
3.0 - 3.5 mm
3.6 - 4.0 mm


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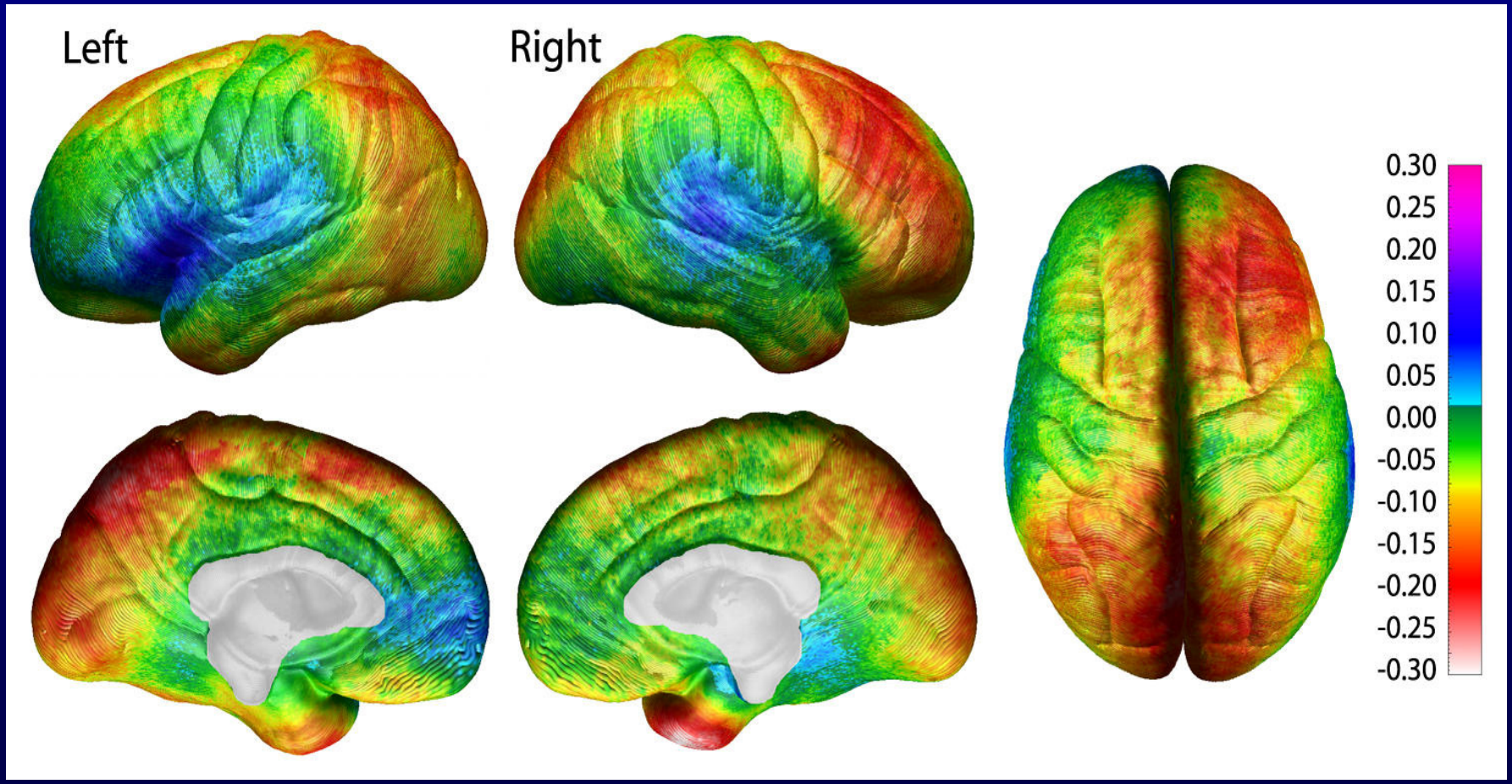
Annualized Rate of Change in Cortical Thickness



Sowell, et al., 2004, *J Neuro*

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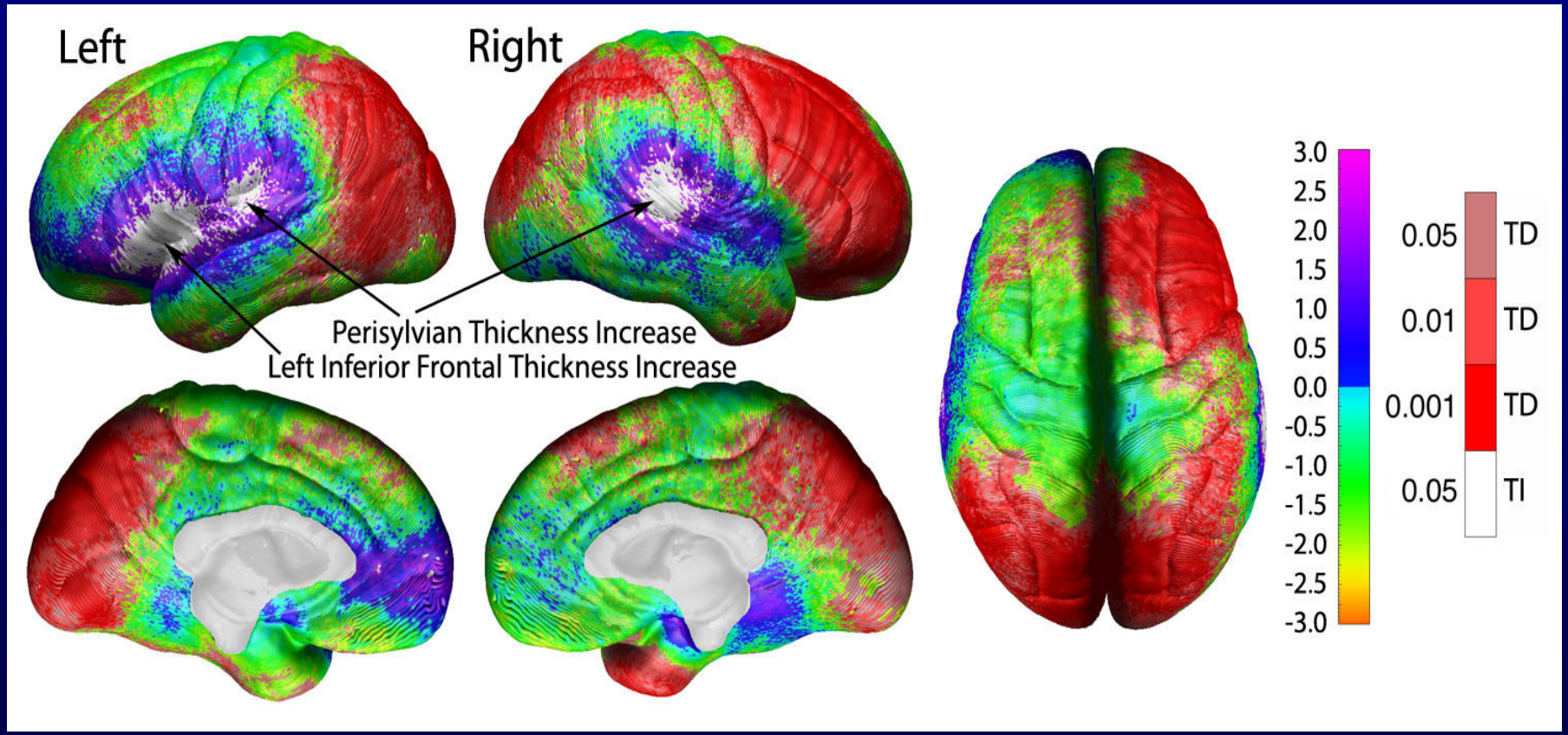
Gray Matter Statistical Map



Sowell, et al., 2004, *J Neuro*

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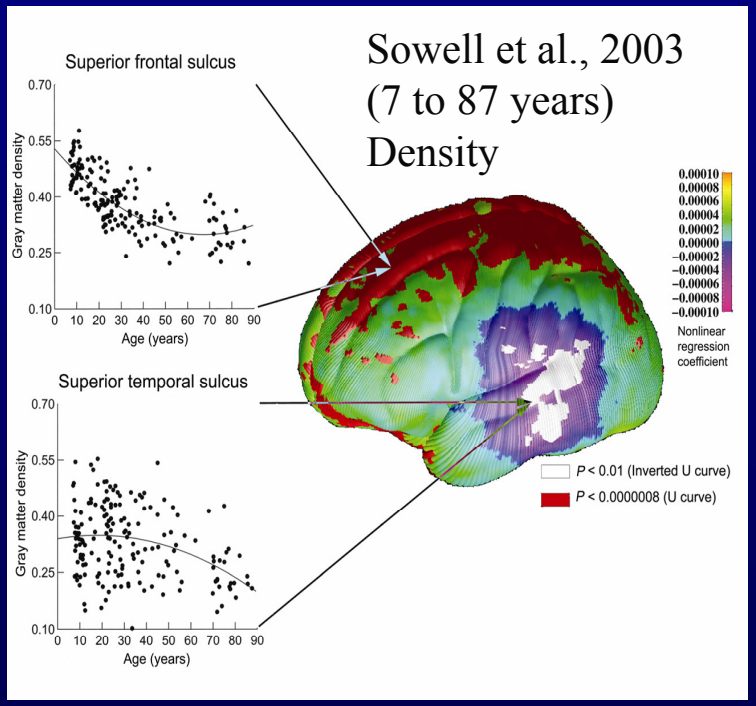
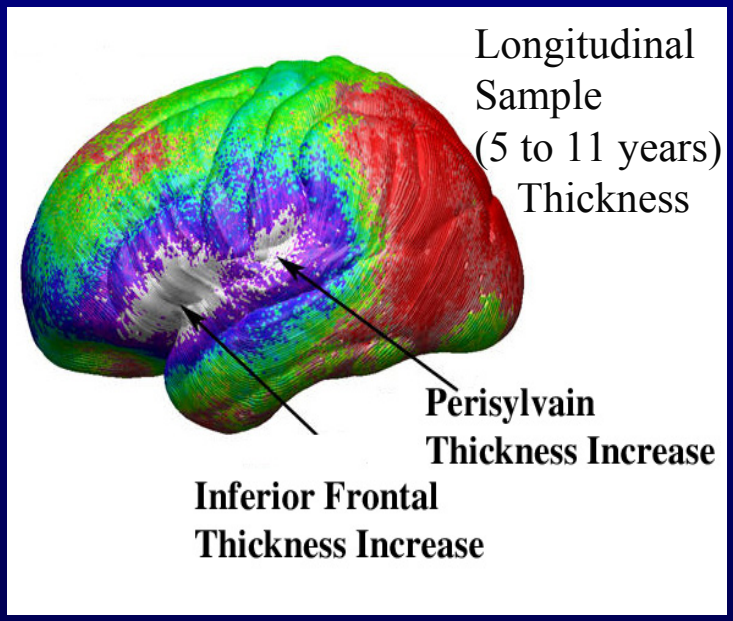

Sowell et al., 2003
(7 to 87 years)
Density
Superior frontal sulcus
Gray matter density
Age (years)
Superior temporal sulcus
Nonlinear regression coefficient
P < 0.01 (Inverted U curve)
P < 0.0000008 (U curve)


Longitudinal
Sample
(5 to 11 years)
Thickness
Perisylvain
Thickness Increase
Inferior Frontal
Thickness Increase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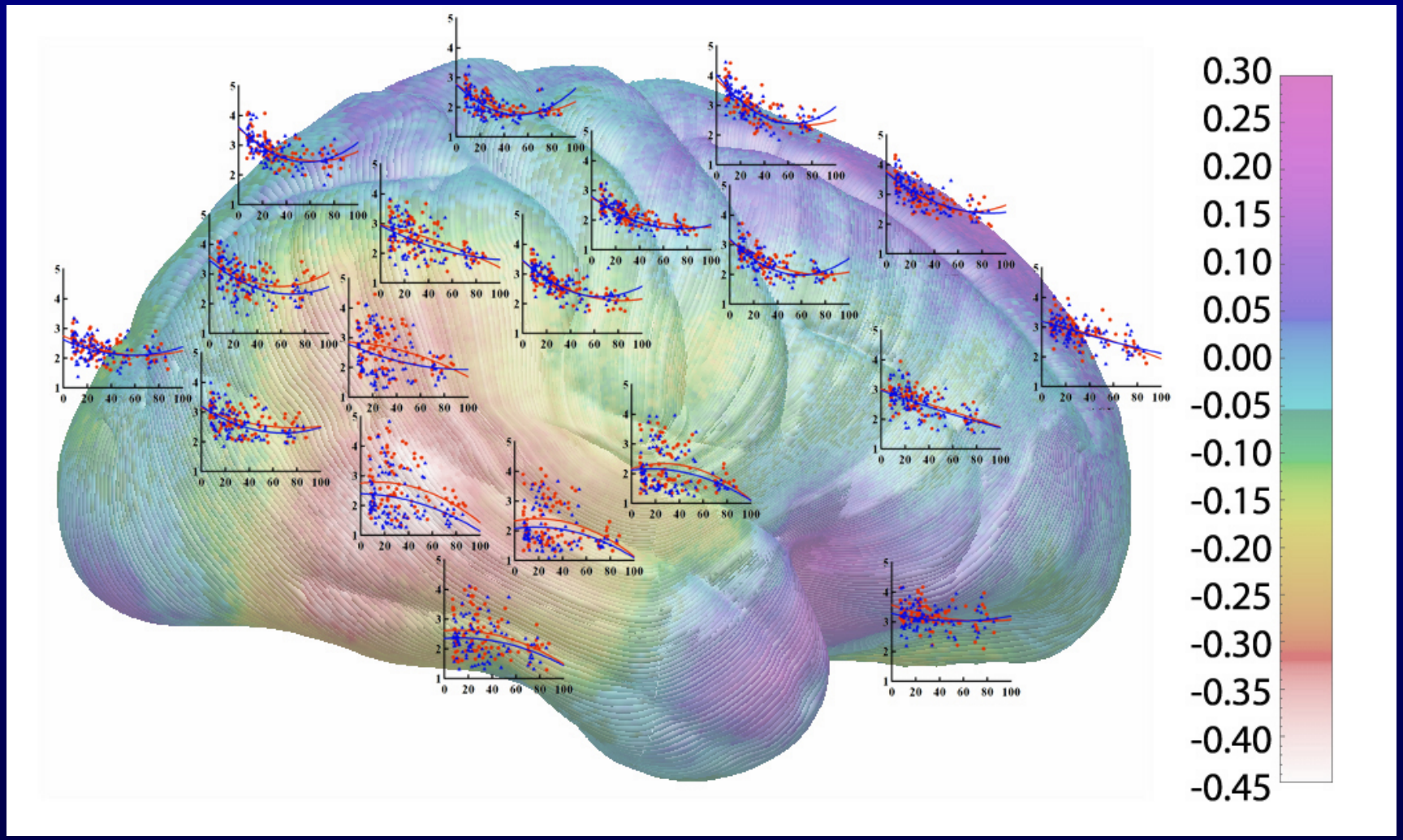
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
-0.45


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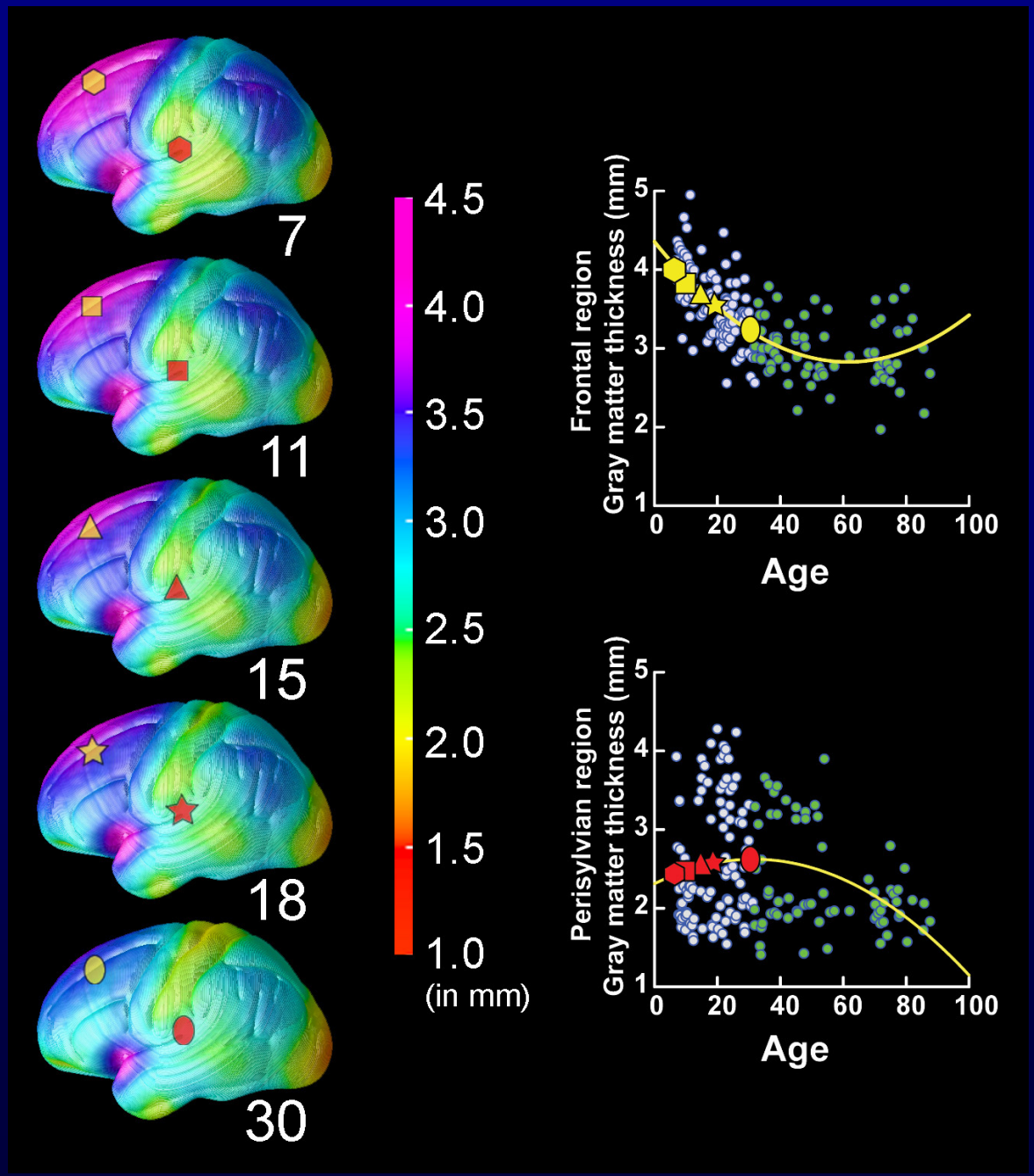
7
11
15
18
30
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
(in mm)
Frontal region
Gray matter thickness (mm)
5
4
3
2
1
0
20
40
60
80
100
Age
Perisylvian region
Gray matter thickness (mm)
5
4
3
2
1
0
20
40
60
80
100
Age


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Newsweek
Tuesday, February 28, 2000
Frontal lobes, which control planning and judgment, are still immature
In the frontal lobes, unused circuits get pruned back well into the 20s
Parietal lobes, seat of visual/spatial ability, lose gray matter through the age of 16
Subcortical regions change, perhaps as habits are laid down
Between the Ears, It's a Construction Site
The brain, say textbooks, is mostly finished growing and connecting by the age of 12 or so. But new studies using MRI show that puberty brings a neuronal growth spurt, followed by the loss of circuits that are not used. Might the pattern of maturation even explain tongue studs?

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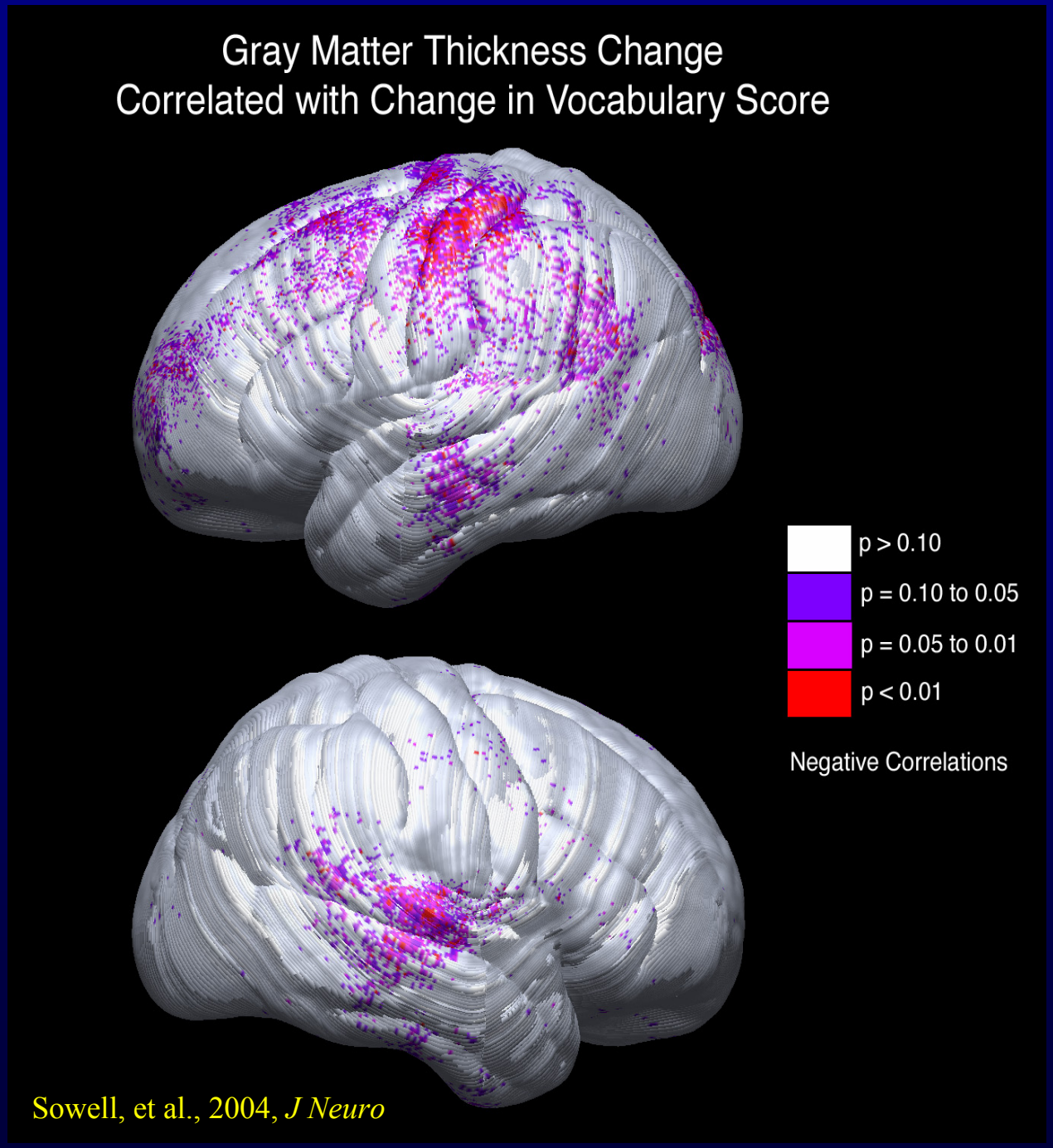
How do developmental changes in brain structure relate to brain function and cognitive abilities?

While it is tempting to speculate that protracted frontal lobe development is at the root of adolescent behavioral eccentricities, unfortunately little is yet known.


Gray Matter Thickness Change
Correlated with Change in Vocabulary Score
p > 0.10
p = 0.10 to 0.05
p = 0.05 to 0.01
p < 0.01
Negative Correlations
Sowell, et al., 2004, J Neuro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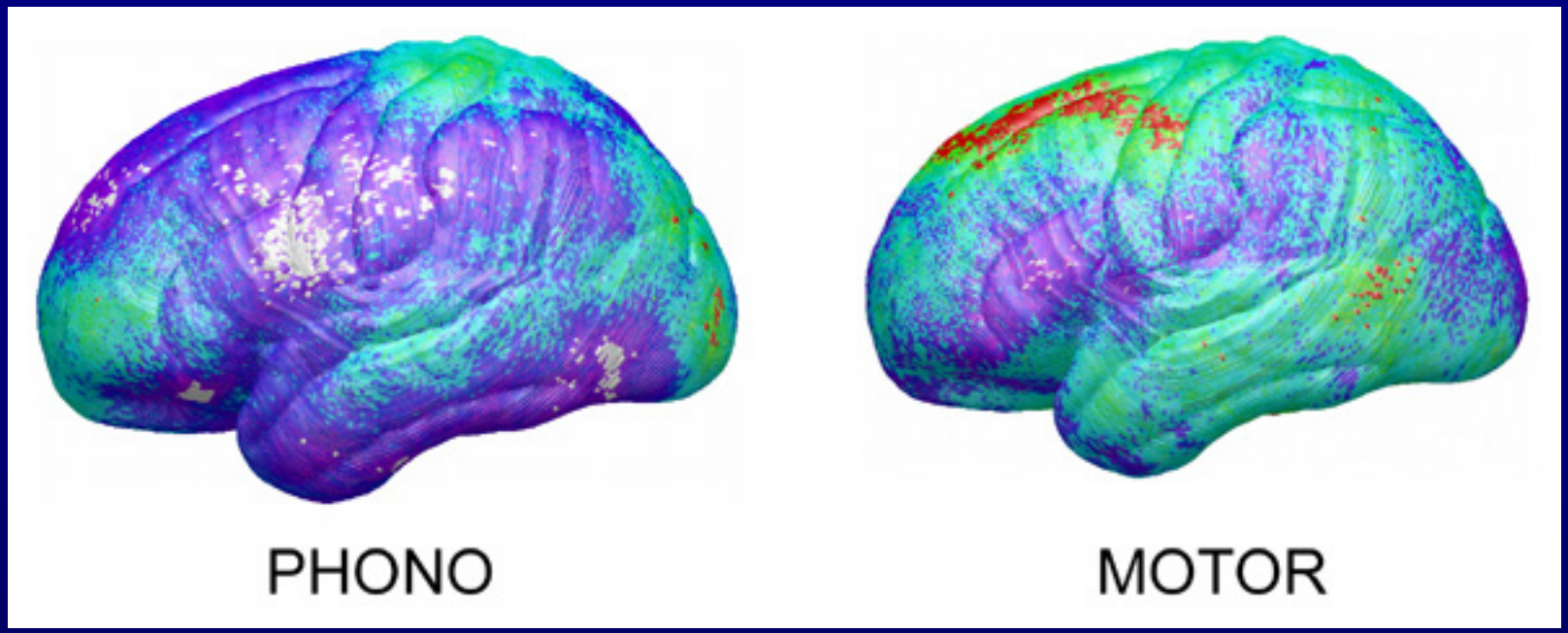

Phonological processing change correlated with thickness change is spatially dissociable from correlations between motor functioning and thickness change. Regions in white are positive (improved performance with increased thickness), and in red are negative (improved performance with decreased thickness).

From Lu et al., 2007, *Cerebral Cortex*.

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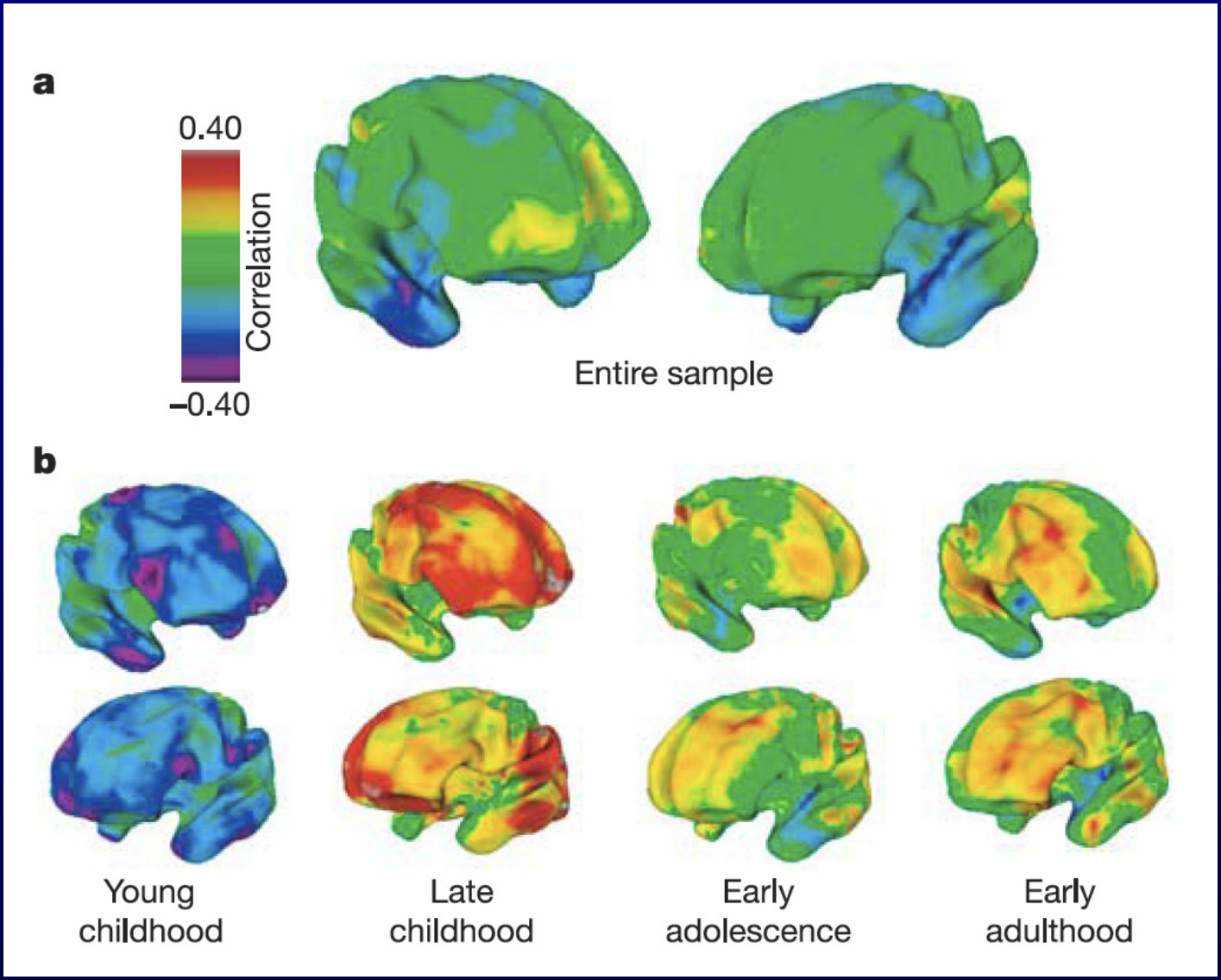

Shaw et al., *Nature*, 2006

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Results from these studies suggest that the direction of relationships between cortical structure and cognitive function seems to be dependent on where you look and when.

General Conclusions: Brain Development

- The tissue within the brain continues to change dynamically during childhood and adolescence even after overall growth has ceased.
  - Frontal cortices are developing most rapidly during the adolescent years.
    - The primary language cortices show a unique pattern of development.

Conclusions: Brain Development

- Perhaps knowing something about cortical structure and brain activation patterns will better predict cognitive abilities than age alone. This might eventually be useful in developing education strategies that are not solely age-based.
  - We are only in the beginning stages of understanding how the brain develops and what factors contribute to changes in brain structure and function.

Collaborators/Contributors

Data Contributions

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